

Recent results on hot topics from Belle

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Abstract

We report a sample of recent and topical physics results based on the data recorded with the Belle detector at the KEK B -factory in Japan.

Keywords: Charm mixing, CP violation, rare B decays, exotic meson

1. Introduction

The Belle experiment is a multitasking magnetic spectrometer that operated for more than a decade at the KEKB asymmetric-energy e^+e^- collider. Before closing down in June 2010 to make way for its upgrade (Belle II), it has succeeded in collecting a world-record sample of data over 1 ab^{-1} near various $\Upsilon(nS)$ resonances. We present herein a sample of recent interesting results from Belle based on its full statistics.

2. Charm mixing and CP violation

Under weak interaction a flavored neutral meson can be represented as a two-state quantum system, leading to possible transition between the two states. The phenomenon going by the name *neutral meson mixing* is intimately related to the difference between the flavor and mass eigenstates of the meson-antimeson system. Such mixing is already well established for K^0 , B^0 and B_s^0 mesons. The observed mixing rates are consistent with the standard model (SM) predictions that depend on the Cabibbo-Kobayashi-Maskawa (CKM) matrix [1] elements, appearing in the short-distance box diagrams for mixing. For D^0 mesons the box diagrams are, however, both Cabibbo and GIM [2] suppressed giving rise to a small contribution. Consequently, D^0 - \bar{D}^0 mixing is dominated by long-distance processes that are difficult to calculate. Theoretical estimates for the mixing parameters $x \equiv \Delta m/\Gamma$ and

$y \equiv \Delta\Gamma/2\Gamma$ range over two to three orders of magnitude [3]. Here, Δm and $\Delta\Gamma$ are the mass and decay width differences between the two D mass eigenstates, and Γ is their average decay width.

Violation of charge-parity (CP) symmetry in the charm sector provides an interesting test for new physics (NP) as the SM predicts a very small asymmetry owing to: a) large Cabibbo and GIM suppression, similar to mixing, and b) a lack of large hierarchy in the down-type quark masses. Among various D decay modes the singly Cabibbo-suppressed (SCS) decays constitute the most promising candidate to probe CP violation [4] with typical SM values are of the order of 10^{-3} . With respect to such percentage effects one needs a good control on the theory prediction, something that is in general lacking in the charm sector due to long-distance effects. Furthermore, with D^0 - \bar{D}^0 mixing being firmly established (see below) one would like to explore possible CP violation in mixing or due to interference between mixing and decay amplitudes.

3. Mixing in $D \rightarrow K\pi$ decays

We search for D^0 - \bar{D}^0 mixing in $D \rightarrow K\pi$ decays [5] by taking a ratio of the time-dependent rate of the wrong-sign (WS) decay $D^0 \rightarrow K^+\pi^-$ to that of the right-sign (RS) decay $D^0 \rightarrow K^-\pi^+$. The RS and WS processes are identified via the decay chain $D^{*\pm} \rightarrow D^0(K^\mp\pi^\pm)\pi_s^\pm$, where one compares the charge of the slow pion π_s with that of the pion arising from the D decay. If the two are the same, it would be a RS decay; else, a WS decay. The RS amplitude is dominated by a Cabibbo-favored (CF) decay $D^0 \rightarrow K^-\pi^+$ with a negligible contribution from D^0 - \bar{D}^0 mixing followed by a doubly Cabibbo-suppressed (DCS) decay $\bar{D}^0 \rightarrow K^-\pi^+$. In contrast, for the WS case the two contributing amplitudes, from the DCS decay $D^0 \rightarrow K^+\pi^-$ and D^0 - \bar{D}^0 mixing followed by the CF decay $\bar{D}^0 \rightarrow K^+\pi^-$, are of similar magnitude. The time-dependent ratio of WS to RS decay rates is thus given by

$$R(t/\tau) \equiv \frac{\Gamma_{\text{WS}}(t/\tau)}{\Gamma_{\text{RS}}(t/\tau)} \approx R_D + \sqrt{R_D} y' \frac{t}{\tau} + \frac{x'^2 + y'^2}{4} \left(\frac{t}{\tau} \right)^2 \quad (1)$$

to the second order in mixing parameters. Here, t is the proper decay time, τ is the average D^0 lifetime, R_D is the ratio of DCS to CF decay rates, $x' = x \cos \delta + y \sin \delta$, and $y' = -x \sin \delta + y \cos \delta$ are the “rotated” mixing parameters with δ being the strong phase difference between the DCS and CF decay amplitudes.

Table 1: Results of the time-dependent fit to $R(t/\tau)$, where DOF denotes the number of degrees of freedom. The uncertainties are statistical and systematic combined.

Test hypothesis	χ^2/DOF	Parameter	Fit result (10^{-3})
Mixing	4.2/7	R_D	3.53 ± 0.13
		y'	4.6 ± 3.4
		x'^2	0.09 ± 0.22
No mixing	33.5/9	R_D	3.864 ± 0.059

Based on a 976 fb^{-1} of data sample, we select $2,980,710 \pm 1885$ RS and $11,478 \pm 177$ WS decay candidates. The proper decay time of these decay candidates is calculated as $t = m_{D^0} \vec{L} \cdot \vec{p} / |\vec{p}|^2$, where \vec{L} is a vector joining the D^0 production and decay vertices, \vec{p} is the D^0 momentum, and m_{D^0} is the nominal D^0 mass [6]. Due care has been taken in incorporating detector resolution effects to the measured t distribution. We fit the obtained time-dependent decay rate ratios according to the expression in Eq. (1). Two hypotheses, with and without D^0 - \bar{D}^0 mixing, are tested and the corresponding results are given in Table 1. The χ^2 difference between the two is 29.3 for 2 degrees of freedom, corresponding to a probability of 4.3×10^{-7} . This means, the no-mixing hypothesis is excluded at a level of 5.1 standard deviations (σ). Our results constitute the first observation of D^0 - \bar{D}^0 mixing from a single e^+e^- collider experiment, and are in agreement with those from experiments at the hadron machine [7].

4. Mixing and CP violation in $D \rightarrow K_s^0 \pi^+ \pi^-$

We simultaneously probe mixing and CP violation [8] by studying time dependence of the Dalitz plot in the self-conjugated decay $D^0 \rightarrow K_s^0 \pi^+ \pi^-$ (denoted by f below). For a given point in the Dalitz plot [$m_+^2 \equiv m^2(K_s^0 \pi^+)$, $m_-^2 \equiv m^2(K_s^0 \pi^-)$], the decay amplitude is

$$\mathcal{M}(t) = \mathcal{A}_f(m_+^2, m_-^2) \frac{e_1(t) + e_2(t)}{2} + \frac{q}{p} \mathcal{A}_{\bar{f}}(m_+^2, m_-^2) \frac{e_1(t) - e_2(t)}{2}, \quad (2)$$

where q, p are the complex coefficients that relate mass to flavor eigenstates, and $e_{1,2}(t) = e^{-(im_{1,2} + \Gamma_{1,2}/2)t}$ with $m_{1,2}$ and $\Gamma_{1,2}$ being the mass and decay

width of the mass eigenstates. The first term is the time-dependent amplitude for the (direct) decay $D^0 \rightarrow K_s^0 \pi^+ \pi^-$, and the second one is the amplitude for D^0 - \bar{D}^0 mixing followed by $\bar{D}^0 \rightarrow K_s^0 \pi^+ \pi^-$. Taking the modulus squared of Eq. (2) gives the time-dependent D^0 decay rate as

$$|\mathcal{M}(t)|^2 = \frac{e^{-\Gamma t}}{2} \left\{ (|\mathcal{A}_f|^2 + \left| \frac{q}{p} \right|^2 |\mathcal{A}_{\bar{f}}|^2) \cosh(\Gamma y t) + (|\mathcal{A}_f|^2 - \left| \frac{q}{p} \right|^2 |\mathcal{A}_{\bar{f}}|^2) \cosh(\Gamma x t) + 2 \mathcal{R} \left(\frac{q}{p} \mathcal{A}_{\bar{f}} A_f^* \right) \sinh(\Gamma y t) - 2 \mathcal{I} \left(\frac{q}{p} \mathcal{A}_{\bar{f}} A_f^* \right) \sinh(\Gamma x t) \right\}. \quad (3)$$

The equivalent quantity in the \bar{D}^0 case also contains terms proportional to $\cosh(\Gamma x t)$, $\cosh(\Gamma y t)$, $\sinh(\Gamma x t)$ and $\sinh(\Gamma y t)$. Thus, by fitting the time-dependent D^0 and \bar{D}^0 decay rates we can determine mixing parameters x and y as well as look for mixing-induced CP violation by checking whether $|q/p|$ deviates from unity or $\text{Arg}(q/p)$ from zero, and if so, by how much.

We use an *isobar model* [9] to describe the decay amplitude $\mathcal{A}_f(m_+^2, m_-^2)$ as $\sum_j a_j e^{i\delta_j} A_j$, where a_j and δ_j are the magnitude and phase of a given intermediate state j , and A_j is the product of a relativistic Breit-Wigner function and Blatt-Weisskopf form factors. Thus in the Dalitz-plot fit we obtain amplitudes and phases of various intermediate states, that lead to the final state of $K_s^0 \pi^+ \pi^-$, in addition to mixing parameters x and y . For no direct CP violation, $\mathcal{A}_f(m_+^2, m_-^2) = \mathcal{A}_{\bar{f}}(m_-^2, m_+^2)$. Otherwise, one needs to separately consider (a_j, δ_j) for D^0 and $(\bar{a}_j, \bar{\delta}_j)$ for \bar{D}^0 decays.

Using a data sample of 921 fb^{-1} recorded near the $\Upsilon(nS)$ ($n = 4, 5$) resonances with Belle, we select $1,231,731 \pm 1633$ signal candidates with a purity above 95%. We perform a time-integrated fit to the Dalitz plot distributions of these events by varying the amplitudes and phases for different intermediate states, separately for D^0 and \bar{D}^0 decays. As the two sets of parameters are found to be consistent within uncertainties, we set $\mathcal{A}_f(m_+^2, m_-^2) = \mathcal{A}_{\bar{f}}(m_-^2, m_+^2)$. Of course, this assumption of no direct CP violation has no bearing for CP violation related to mixing. Next we follow a two-step fit procedure. In the first step, we fit to a combined sample of D^0 and \bar{D}^0 with the fit observables (x, y) , the D^0 lifetime τ , some timing resolution parameters, and isobar model parameters (a_j, δ_j) . In the second step, CP violation related to mixing is allowed resulting in two more fit observables: $|q/p|$ and $\phi = \text{Arg}(q/p)$. Results of the above two fits are listed in Table 2. The two sets of mixing parameters obtained are pretty much identical, and they constitute a 2.5σ evidence for D^0 - \bar{D}^0 mixing. With $|q/p|$ and

ϕ being consistent with unity and zero, respectively, there is no CP violation either in D^0 - \bar{D}^0 mixing or due to interference between mixing and decay.

Table 2: Results for mixing parameters x and y from the no and with CP violation (CPV) case. The uncertainties are respectively statistical, experimental systematic, and the error due to amplitude model.

Fit type	Parameter	Fit result
No CPV	x (%)	$0.56 \pm 0.19^{+0.03}_{-0.09} {}^{+0.06}_{-0.09}$
	y (%)	$0.30 \pm 0.15^{+0.04}_{-0.05} {}^{+0.03}_{-0.06}$
With CPV	x (%)	$0.56 \pm 0.19^{+0.04}_{-0.08} {}^{+0.06}_{-0.08}$
	y (%)	$0.30 \pm 0.15^{+0.04}_{-0.05} {}^{+0.03}_{-0.06}$
	$ q/p $	$0.90^{+0.16}_{-0.15} {}^{+0.05}_{-0.04} {}^{+0.06}_{-0.05}$
	ϕ ($^\circ$)	$-6 \pm 11 \pm 3^{+3}_{-4}$

5. Search for CP violation in $D^0 \rightarrow \pi^0 \pi^0$

The $D^0 \rightarrow \pi^0 \pi^0$ decay, a typical SCS one, is expected to exhibit large CP violation in several NP models such as those with large chromomagnetic dipole operators [10] and the triplet model [11]. The enhanced CP asymmetry value could lie anywhere between 1% and 8%. Further motivation for our study came from an early measurement by LHCb [12], supported by CDF [13], suggesting a 3.5σ effect on the difference of direct CP asymmetries (ΔA_{CP}) between $D^0 \rightarrow K^+ K^-$ and $D^0 \rightarrow \pi^+ \pi^-$ decays. Though the current world average for ΔA_{CP} stands 2.3σ away from zero [18], there exists a good deal of theoretical motivation [10, 11, 14] to look for CP violation in $D^0 \rightarrow \pi^0 \pi^0$. Experimentally, the previous result from CLEO [15] was consistent with zero with an uncertainty of 4.8% – as big as the NP prediction.

We measure the time-integrated CP asymmetry in the $D^0 \rightarrow \pi^0 \pi^0$ and $D^0 \rightarrow K_s^0 \pi^0$ decays [16] using 966 fb^{-1} of data collected with Belle. In the process $D^{*+} \rightarrow D^0 \pi_s^+$ coming from $e^+ e^- \rightarrow c \bar{c}$, the charge of the low-momentum or “slow” pion π_s^+ determines the flavor of the neutral charm

meson (whether it is a D^0 or a \bar{D}^0). The measured asymmetry

$$A_{\text{rec}} = \frac{N_{\text{rec}}^{D^{*+} \rightarrow D^0 \pi_s^+} - N_{\text{rec}}^{D^{*-} \rightarrow \bar{D}^0 \pi_s^-}}{N_{\text{rec}}^{D^{*+} \rightarrow D^0 \pi_s^+} + N_{\text{rec}}^{D^{*-} \rightarrow \bar{D}^0 \pi_s^-}}, \quad (4)$$

where N_{rec}^i is the number of reconstructed events tagged as i , has three contributions: the underlying CP asymmetry A_{CP} , the forward-backward asymmetry (A_{FB}) due to γ - Z^* interference in $e^+e^- \rightarrow c\bar{c}$ and higher-order QED processes, and the detection asymmetry between positively and negatively charged pions ($A_{\epsilon}^{\pi_s}$). We subtract the A_{rec} measured in the CF decay $D^0 \rightarrow K^-\pi^+$ (“untagged”) from $D^{*+} \rightarrow D^0\pi_s^+$; $D^0 \rightarrow K^-\pi^+$ (“tagged”) to estimate $A_{\epsilon}^{\pi_s}$. The implicit assumption here is that both D^* and D mesons have the same A_{FB} value. After correcting for $A_{\epsilon}^{\pi_s}$, one is left with

$$A_{\text{rec}}^{\text{cor}} = A_{CP} + A_{\text{FB}}(\cos \theta^*), \quad (5)$$

where θ^* is the D^{*+} polar angle in the center of mass (CM) frame. While A_{CP} is independent of kinematics, A_{FB} is an odd function of $\cos \theta^*$. Making use of this important distinction, we obtain $A_{CP} = [A_{\text{rec}}^{\text{cor}}(\cos \theta^*) + A_{\text{rec}}^{\text{cor}}(-\cos \theta^*)]/2$ and $A_{\text{FB}} = [A_{\text{rec}}^{\text{cor}}(\cos \theta^*) - A_{\text{rec}}^{\text{cor}}(-\cos \theta^*)]/2$.

Based on a total signal yield of $34,460 \pm 273$ $D^0 \rightarrow \pi^0\pi^0$ events, we obtain $A_{CP} = [-0.03 \pm 0.64(\text{stat}) \pm 0.10(\text{syst})]\%$, which improves over the previous results [15] by an order of magnitude and shows no hint for CP violation. We also measure $A_{CP}(D^0 \rightarrow K_s^0\pi^0) = [-0.21 \pm 0.16(\text{stat}) \pm 0.07(\text{syst})]\%$, which supersedes Belle’s earlier result [17]. After subtracting CP violation due to K^0 - \bar{K}^0 mixing, the CP asymmetry for $D^0 \rightarrow \bar{K}^0\pi^0$ is found to be $(+0.12 \pm 0.16 \pm 0.07)\%$, again consistent with no CP violation.

6. Lepton forward-backward asymmetry in $B \rightarrow X_s \ell^+ \ell^-$

The flavor-changing neutral current (FCNC) transition $b \rightarrow s \ell^+ \ell^-$ ($\ell = e, \mu$) is forbidden at tree level in the SM. However, it can occur at higher order via electroweak loop (penguin) and W^+W^- box diagrams. The corresponding decay amplitudes are expressed in terms of the effective Wilson coefficients [19]: C_7 for the electromagnetic penguin, C_9 and C_{10} for the vector and axial-vector electroweak contributions, respectively [20]. In presence of NP contributions, these coefficients are expected to differ from SM predictions, leading to a dramatic change in the decay rate and angular distributions of

the $b \rightarrow s\ell^+\ell^-$ transition [21]. For instance, the lepton forward-backward asymmetry in the $B \rightarrow X_S\ell^+\ell^-$ decays,

$$A_{\text{FB}} = \frac{\Gamma(B \rightarrow X_S\ell^+\ell^-; \cos\theta > 0) - \Gamma(B \rightarrow X_S\ell^+\ell^-; \cos\theta < 0)}{\Gamma(B \rightarrow X_S\ell^+\ell^-; \cos\theta > 0) + \Gamma(B \rightarrow X_S\ell^+\ell^-; \cos\theta < 0)}, \quad (6)$$

where θ is the angle between the $\ell^+(\ell^-)$ and the B meson momentum in the $\ell^+\ell^-$ CM frame and X_S is a hadronic system containing an s quark, exhibits an excellent sensitivity for physics beyond the SM.

Motivated by this, we perform the first measurement of A_{FB} in the inclusive $B \rightarrow X_S\ell^+\ell^-$ decays as a function of the dilepton invariant mass squared $q^2 = m_{\ell^+\ell^-}^2$ [22], using 772×10^6 $B\bar{B}$ pairs collected at the $\Upsilon(4S)$ resonance. By inclusive here one means a sum of several exclusive hadronic final states representing the X_S system. We reconstruct B mesons in 18 hadronic final states with $X_S \equiv \{K\}\{n\pi\}$, $K = K^\pm, K_S^0$ and $n = 1\dots 4$ of which at most one pion can be neutral, together with two oppositely charged leptons (electrons or muons). In case of B^0 (\bar{B}^0) decays, only self-tagging modes with a K^+ (K^-) are utilized. Signal events are identified with two kinematic variables, calculated in the $\Upsilon(4S)$ rest frame: the beam-energy constrained mass $M_{\text{bc}} = \sqrt{E_{\text{beam}}^2 - |\vec{p}_B|^2}$ and the energy difference $\Delta E = E_B - E_{\text{beam}}$, where E_{beam} is the beam energy, and (E_B, \vec{p}_B) are the reconstructed energy and momentum of the B -meson candidate. To reduce contamination from the $e^+e^- \rightarrow q\bar{q}$ ($q = u, d, s, c$) continuum background, we use a neural network mostly based event topology and B vertex-fit quality. Charmonia contributions from $B \rightarrow X_S J/\psi[\psi(2S)]$ with $J/\psi[\psi(2S)] \rightarrow \ell^+\ell^-$, are suppressed by rejecting (“vetoing”) events with a dilepton invariant mass in the following two ranges: -400 to $150 \text{ MeV}/c^2$ (-250 to $100 \text{ MeV}/c^2$) and -250 to $100 \text{ MeV}/c^2$ (-150 to $100 \text{ MeV}/c^2$) around the nominal J/ψ and $\psi(2S)$ mass [6] mass for the electron (muon) channel.

In total, $140 \pm 19(\text{stat})$ $B \rightarrow X_S e^- e^+$ and $161 \pm 20(\text{stat})$ $B \rightarrow X_S \mu^+ \mu^-$ signal candidates are selected in the data sample. To study the q^2 dependence of A_{FB} , we divide the data into four q^2 bins: $[0.2, 4.3]$, $[4.3, 7.3(8.1)]$, $[10.5(10.2), 11.8(12.5)]$, and $[14.3, 25.0] \text{ GeV}^2/c^4$ for the electron (muon) channel, where the gap regions correspond to the veto described earlier. The A_{FB} value is found to be consistent with the SM prediction in the two intermediate q^2 bins, while it deviates from the SM in the lowest q^2 bin by 1.8σ (including the systematic uncertainty). Results in the last two bins exclude $A_{\text{FB}} < 0$ at a 2.3σ level.

7. Observation of the decay $B^0 \rightarrow \eta' K^*(892)^0$

The $B^0 \rightarrow \eta' K^*(892)^0$ decay proceeds via the $b \rightarrow s$ penguin and Cabibbo-suppressed $b \rightarrow u$ tree diagrams. There is a destructive interference between two contributing amplitudes leading to a small decay branching fraction. The interference pattern could also give rise to a large direct CP violation. Typical branching fraction values calculated within the framework of perturbative QCD [23], QCD factorization [24], soft collinear effective theory [25] and $SU(3)$ flavor symmetry [26] are in the range 1.2–6.3%. In the past, Belle [27] and BABAR [28] have searched for $B^0 \rightarrow \eta' K^*(892)^0$ with the latter reporting the first evidence at a 4σ level. So far, CP violation has not been probed in the decay.

We search for $B^0 \rightarrow \eta' K^*(892)^0$ [29] using a data sample of 772×10^6 $B\bar{B}$ pairs recorded at the $\Upsilon(4S)$ resonance. The decay candidates are reconstructed from the subsequent decay modes $\eta' \rightarrow \eta\pi^+\pi^-$, $\eta \rightarrow \gamma\gamma$ and $K^*(892)^0 \rightarrow K^+\pi^-$. Based on an extended maximum likelihood fit to their distributions of M_{bc} , ΔE , continuum suppression variable, and the cosine of the K^* helicity angle, we extract a signal yield of 31 ± 9 events with a significance of 5σ , including systematic uncertainties. This constitutes the first observation of the decay channel. The yield is translated to a branching fraction $\mathcal{B}[B^0 \rightarrow \eta' K^*(892)^0] = [2.6 \pm 0.7(\text{stat}) \pm 0.2(\text{syst})] \times 10^{-6}$, in a good agreement with theory predictions. We also measure direct CP violation by splitting the obtained yield according to the flavor of the B meson, based on the sign of the daughter kaon from the K^* decay. The obtained result, $A_{CP} = -0.22 \pm 0.29(\text{stat})0.07(\text{syst})$, is consistent with no CP violation.

8. An amplitude analysis of $B \rightarrow J/\psi K\pi$

Recently, a number of new charmonium-like states have been observed at the B factories and elsewhere. Some of them especially the charged ones look very much like exotic, defying predictions of the quark model. The first one in the series, the $Z_c(4430)^+$, was discovered by Belle in the $\psi(2S)\pi^+$ invariant mass spectrum in $B^0 \rightarrow \psi(2S)K^-\pi^+$ [30], followed by two more states, the $Z_c(4050)^+$ and $Z_c(4250)^+$, in $B^0 \rightarrow \chi_{c1}K^-\pi^+$ decays [31]. Lately, BESIII has joined the game by observing $Z_c(3900)^+$ in the $J/\psi\pi^+$ invariant mass spectrum in $Y(4260) \rightarrow J/\psi\pi^+\pi^-$ [32]. In a back-to-back publication [33], Belle corroborated the finding.

Motivated by these exciting results, we perform an amplitude analysis [35] of the decay $B^0 \rightarrow J/\psi K^- \pi^+$, with $J/\psi \rightarrow \mu^+ \mu^-$ or $e^+ e^-$, using a data sample of 772×10^6 $B\bar{B}$ pairs. Our analysis strategy is similar to a recent study of $B^0 \rightarrow \psi(2S) K^- \pi^+$ [34]. In addition to the known $Z_c(4430)^+$ state, we find a new charmonium-like state $Z_c(4200)^+$ in the $J/\psi \pi^+$ invariant mass spectrum with a significance exceeding 6σ . The minimal quark content of this state is exotic: $|c\bar{c}u\bar{d}\rangle$. Its mass and decay width are measured to be $[4196^{+31}_{-29}(\text{stat})^{+17}_{-13}(\text{syst})]$ MeV/ c^2 and $[370 \pm 70(\text{stat})^{+70}_{-132}(\text{syst})]$ MeV, respectively. The preferred spin-parity quantum numbers are $J^P = 1^+$.

9. Summary and outlook

Though close to five years have passed by since its data taking, Belle continues to produce high quality results. A small sample of those based on the full statistics are presented here. That includes: a) first observation of D^0 - \bar{D}^0 mixing using $D \rightarrow K\pi$ decays in e^+e^- collisions, b) a 2.5σ evidence for charm mixing and no hint for CP violation in $D^0 \rightarrow K_S^0 \pi^+ \pi^-$, c) an order-of-magnitude improvement over the previous results for A_{CP} in the decay $D^0 \rightarrow \pi^0 \pi^0$, d) a 1.8σ difference with respect to the SM prediction in the lepton forward-backward asymmetry at low q^2 in the inclusive $B \rightarrow X_S \ell^+ \ell^-$ decays, e) first observation of the charmless hadronic decay $B^0 \rightarrow \eta' K^*(892)^0$, and f) observation of a new charged charmonium-like state in $B^0 \rightarrow J/\psi K^- \pi^+$. Such kind of unique explorations at the next-generation e^+e^- flavor factory will continue with the upcoming Belle II experiment [36].

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